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# Statistical comparison of central England annual and monthly mean air temperature variability, 1660–1977*

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**Summary**

A series of surface atmospheric temperature values in central England from 1660 to 1977 is used to compare the variability of the annual mean with that of the individual monthly means. Firstly, correlation analysis of yearly and monthly data yields a mean correlation coefficient of + 0·45. On investigating the correlation with a Gaussian low-pass filter for a period $T > 30$ a (where 'a' denotes 'year') it is found that the mean correlation coefficient increases to + 0·65. Significant (> 99 per cent) maxima of correlation occur in spring (March, + 0·89) and autumn (October, + 0·81), and significant minima in winter (February, + 0·50) and summer (June, + 0·52).

The low-pass filtered annual and monthly data display remarkable agreement with respect to the increase in temperature from 1694 to 1731/32. Otherwise, however, very clear differences are to be seen, including the increase in temperature in the first half of the twentieth century. The most recent relative maximum in annual values was reached in 1946, whereas the May values peaked as early as 1917 and the October values not until 1964. Finally, comparison of the variance spectra of the annual and monthly data indicates similarities in the range of relatively long periods $T > 50$ a, and in connection with quasi-biennial fluctuations.

## Introduction

Long-term series of meteorological measurements (see, for example, Lamb 1972, 1977; v. Rudloff 1967; Schönwiese 1974) reflect the variability of our climate. Whereas the year-to-year fluctuations mostly present a very confusing picture, it is possible, with the aid of statistical methods, to codify this variability in terms of its components and to represent it in summary fashion.

Thus, low-pass filters (Mitchell 1966; Schönwiese 1978d; Taubenheim 1969) have the effect of showing up long-term trends and largely suppressing the components of fluctuation which have a relatively short period, for example $T < 10$ a or $T < 30$ a (where 'a' denotes 'year'). Interstation comparison of this type of filtered data makes it possible to consider parallels and phase shifts in long-term fluctuations, something which the direct year-to-year variation reveals either not at all or only very dimly. Such an investigation has recently been published (Schönwiese 1978d) for some temperature series in Europe and for the series in the northern hemisphere.

Apart from the long-term fluctuations—regular or irregular—there is a further aspect of particular interest: how is the variability of a series of measurements distributed throughout the range of periods,

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and are there signs of cyclic variability? The questions are answered by means of spectral variance analysis (Mitchell 1966; Panofsky and Brier 1958; Schönwiese 1969; Walk 1970) and numerical band-pass filtering (Brier 1961; Mitchell 1966; Schönwiese 1974, 1975).

The variance spectrum gives the distribution of the variance in relation to definite intervals of period and frequency. By means of numerical band-pass filtering it is possible to consider the variability of the time series in isolation within more or less narrowly limited intervals of period and frequency. Cospectrum and cross-spectrum analysis may be used, in conjunction with coherence analysis (Doberitz 1968; Fleer 1975; Walk 1970) to compare the variability of two time series, also in relation to period or frequency.

If consideration is limited to the range of periods $T > 1$ a—the 'climatological scale' (Schönwiese 1978c)—and to neoclimatological series, that is to say, those based on direct measurements, it is only in a few instances that detailed discussion can be undertaken for a span of several hundred years. The longest closed and homogeneous climatological time series available in the form of monthly mean values is the series of surface air temperatures for central England (Manley 1974), which begins in 1659. Statistical analyses of the variability observed in this series are already to hand (Manley 1974; Schönwiese 1978a, 1978b, 1978d), and serve different goals.

In relation to the long-term ($T > 30$ a) component of annual data fluctuation there are relative maxima in 1732, 1828, 1867, and 1946, and relative minima in 1694, 1813, 1840 and 1887; see the continuous curve in the first part of Figure 1, and compare also Schönwiese 1978d. For the variance as related to frequency, significant (the word implying here values above the 80 per cent confidence limit) maxima occur in connection with periods of approximately 100 a, approximately 25 a, 5·1 a, 3·4 a, 3·1 a and 2·2 a, and less significant maxima in connection with periods of 14 a and 7·4 a; see Figure 2, upper curve, and compare also Schönwiese 1978a. In the following sections these data are more closely analysed and discussed.

Before proceeding, however, one more consideration of general interest: statistical analyses, the methods of which are partly discussed here, are useful not only to provide an exact description of the data from various points of view. They ought also not to be underestimated in the interpretation of observations, in the search for the causes of variability, and in the problem of the predictability of the latter. They may also help to provide bearings for the climatic models in relation to the phenomena to be reproduced. Moreover, statistics are increasingly being incorporated directly into the models, particularly where success is lacking in the only partly applicable three-dimensional models of the general circulation.

**Connection between the annual and monthly means**

The following question will now be examined within the framework of neoclimatology and the range of periods $T > 1$ a: how far is the year-to-year variability influenced by the variability of the individual months? In an alternative formulation: over periods of a few or many years is it possible to find interannual trends in the means of individual months, as can be done for the annual means?—or are the long-term trends of annual means the result of a wholly irregular interplay of the monthly trends, and thus to be regarded as random?

These questions are of essential importance in the search for the causes of long-term fluctuations and in the discussion of their predictability, because if a wholly irregular picture emerges the fluctuations taking place must be regarded as the product of internal stochastic fluctuations in the climatic system and in the general circulation of the atmosphere; if not, non-random processes, including external causes, come into consideration as well (Mitchell 1976; US Committee for the GARP, 1975).

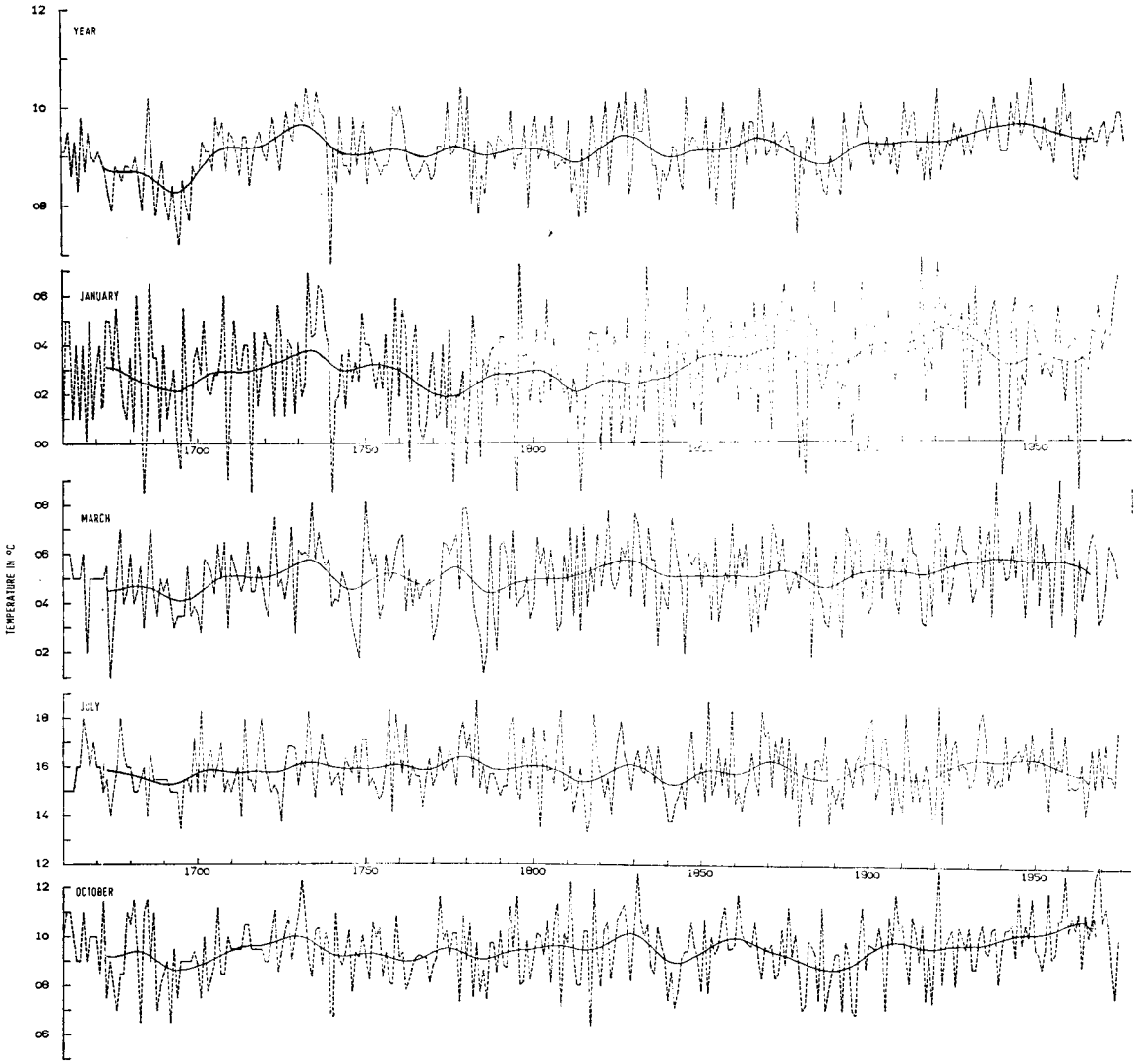


Figure 1. Mean air temperature in central England for the year as a whole and the individual months of January, March, July and October over the periods 1660–1977 (for the annual means) and 1660–1976 (for the monthly means). The dashed curves represent unfiltered values, the continuous curves values filtered with a Gaussian low-pass filter for $T > 30$ a.

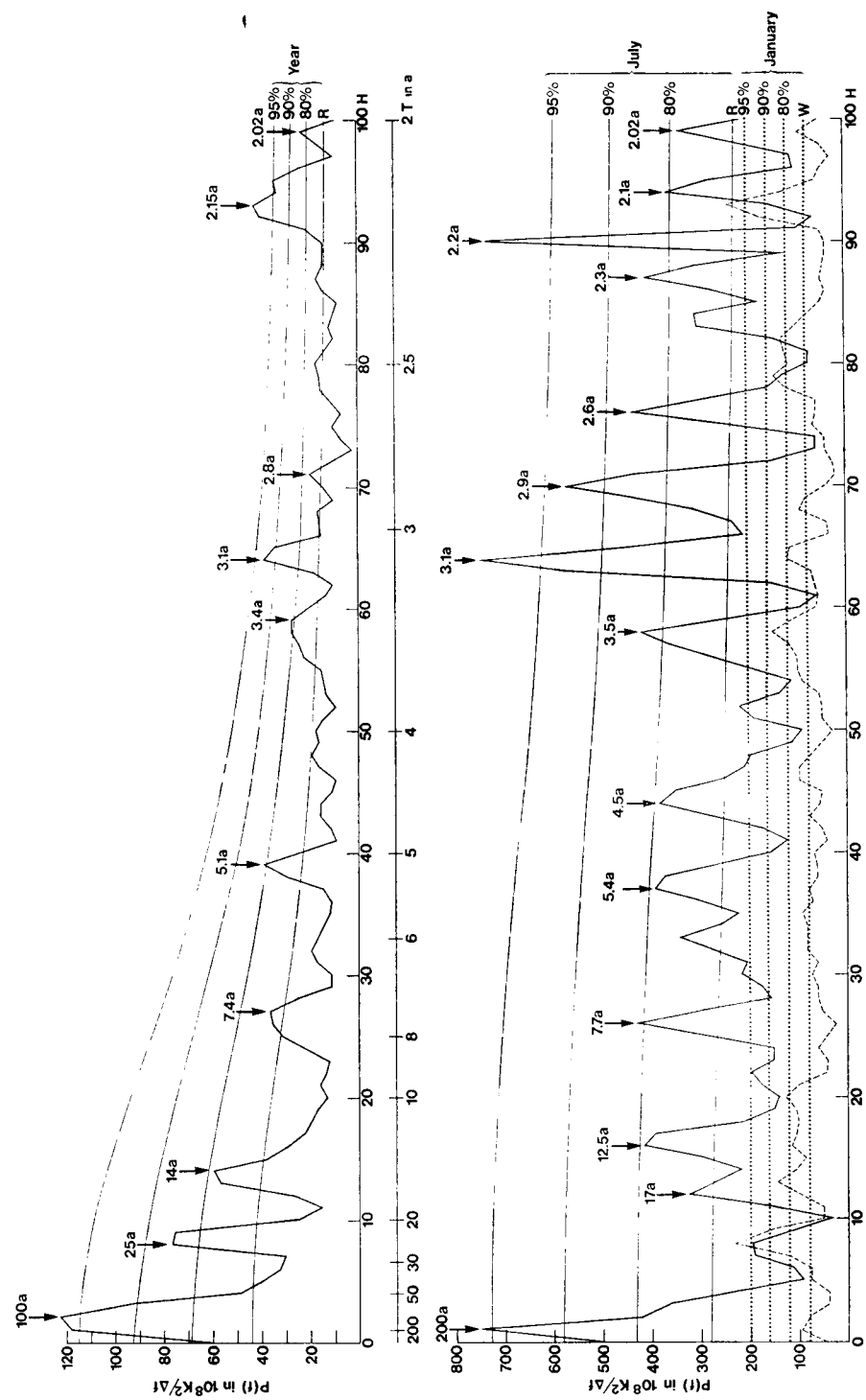


Figure 2. The variance spectra of annual means (upper curve) and July and January means (lower curves, continuous and dashed respectively) of temperature in central England, 1660–1969. The continuous and dotted lines labelled with percentages are the confidence limits determined by the $^2$ test. 'R' denotes the red part of the spectrum, 'W' the white. The maximum lag of each autocorrelation function is 100 data intervals.

An attempt will now be made to answer these questions using the example of the temperature series for central England already mentioned. Table I gives the Pearson linear correlation coefficients (Haseloff and Hoffmann 1970; Sachs 1974) and their 90 per cent confidence intervals (Haseloff and Hoffmann 1970), as derived by comparing the annual means with means of the individual months over the period from 1660 to 1969.

It will be seen that the annual means are correlated with the means of all the months. The mean correlation coefficient amounts to + 0·45, and the confidence intervals fluctuate between ± 0·06 and ± 0·08. The differences with respect to the individual months are not very large: February has the maximum value, at + 0·56, May the minimum, at + 0·35. A 'double wave' is in evidence, with a relatively high correlation between the annual values, on the one hand, and the late winter and high summer values, on the other, and with a relatively low correlation between the annual values and the late spring and early winter values. However, these differences are significant at the 90 per cent level only from winter to spring (cf. the confidence intervals).

Certainly, a *t*-test of the correlation coefficients (Sachs 1974) indicates that even in connection with the smallest correlation coefficient (May, + 0·35) the significance of the correlation in itself is greater than 99·9 per cent. It should not be overlooked, however, that the computed coefficients lie in a position approximately midway between an ideal connection and no connection at all and, if anything, do not quite reach this position. Consequently, an approximate balance is held by parallel and opposing trends. In this connection the reader should see the dashed curves in Figure 1, in which, as an example, the means for January, March, July and October are represented in comparison with the annual means.

The next step is to follow the procedure detailed in Schönwiese 1978d for the purpose of applying a Gaussian low-pass filter (Mitchell 1966; Schönwiese 1978d; Taubenheim 1969) to all the values in such a way that all components of fluctuation with $T < 30$ a are largely suppressed. It should be mentioned here that because of their much more favourable filter response function Gaussian low-pass filters and similar methods are much to be preferred to moving averages which themselves also operate as low-pass filters. Because of the secondary maxima of the filter response function which arise in the process of taking running means, it is impossible to avoid distorting effects, particularly when making step-wise multiple applications.

**Table I.** *Correlation coefficients between the annual and monthly means of surface air temperature in central England calculated over the period from* 1660 *to* 1969.

| | Unfiltered values | Filtered values |
|---|---|---|
| Year — January | + 0·47 ± 0·07 | + 0·54 ± 0·07 |
| Year — February | + 0·56 ± 0·06 | + 0·50 ± 0·07 |
| Year — March | + 0·55 ± 0·06 | + 0·89 ± 0·02 |
| Year — April | + 0·48 ± 0·07 | + 0·78 ± 0·04 |
| Year — May | + 0·35 ± 0·08 | + 0·60 ± 0·06 |
| Year — June | + 0·41 ± 0·08 | + 0·52 ± 0·07 |
| Year — July | + 0·45 ± 0·08 | + 0·60 ± 0·06 |
| Year — August | + 0·48 ± 0·07 | + 0·56 ± 0·07 |
| Year — September | + 0·43 ± 0·08 | + 0·75 ± 0·04 |
| Year — October | + 0·45 ± 0·08 | + 0·81 ± 0·03 |
| Year — November | + 0·38 ± 0·08 | + 0·66 ± 0·06 |
| Year — December | + 0·37 ± 0·08 | + 0·63 ± 0·06 |
| Arithmetic mean | + 0·45 | + 0·65 |
| Standard deviation | ± 0·07 | ± 0·13 |

*Note.* Concerning the filtered values, a Gaussian low-pass filter was applied which largely suppressed all components of fluctuation with $T < 30$ a. The 90 per cent confidence intervals are shown next to the correlation coefficients.

The result of the correlation analysis of the values treated with a Gaussian low-pass filter to suppress periods having $T < 30$ a is as follows: there is a significant increase in the correlation coefficients, the mean being + 0·45 for the unfiltered values and + 0·65 for the filtered ones. The 90 per cent confidence intervals of the correlation coefficients of the filtered data fluctuate between ± 0·02 and ± 0·07.

The differences between the correlation coefficients are much higher for the filtered than for the unfiltered values, the standard deviations of the coefficients being ± 0·13 as against ± 0·07. It is surprising that the smallest correlation coefficient of the filtered values, namely + 0·50, for February, coincides with the highest coefficient of the unfiltered values, + 0·56, also in February.

However, the 'double wave' of the correlation coefficients for the unfiltered data is less pronounced than that for the filtered data; more important, it is much less significant statistically. The correlation maxima of the filtered values (March, + 0·89 and October, + 0·81), and the corresponding minima (February, + 0·50 and June, + 0·52) remain significant if the confidence interval is increased from 90 to 99 per cent. Consequently, the differences between correlation coefficients must be seen as more important in connection with the filtered values.

It is conceivable that the high correlation between the annual values and the early spring and autumn data is connected through a feedback mechanism with the snow cover, which is particularly variable at those times of year, and with its albedo, in such a way that the occurrence or non-occurrence of a snow cover in these seasons has a particularly strong influence on the annual values. Interestingly enough, however, this holds only for the part of the spectrum of temperature fluctuation where the periods are relatively long, here $T > 30$ a.

It is obvious from a careful interpretation of the results that in the band where periods are relatively long—and it should be noted that the limit $T > 30$ a is, of course, arbitrary and in need of fuller explanation—the stochastic component of fluctuation is smaller than in the band of short periods. Consequently, it may be hoped that investigation of the appropriate long-term trends will lead more quickly to knowledge of systematic, that is to say non-stochastic, processes and their causes.

**The comparison of long-term trends**

It seems reasonable, therefore, to look more closely at the long-term trends. This will be done with the aid, once again, of the temperature series for central England, modified by the use of a Gaussian low-pass filter of the type mentioned. The resultant annual and selected monthly values are shown by the continuous curves in Figure 1.

In connection with the annual values the following trends are particularly striking: the rise from the relative minimum of 1694 to the relative maximum of 1732, which according to Lamb (1972, 1977) is synonymous with the end of the culmination of the 'little ice-age' (cf. also Schönwiese 1978d); the less pronounced fall to the relative minimum of 1813; further, the rise from the relative minimum of 1887 to the most recent relative climatic optimum (Schönwiese 1978d) corresponding to the relative maximum of 1946, where this rise, according to Flohn (1978), is to be related to the end of the 'little ice-age'. Between these lie some less striking trends, namely the rise of 1813–28 and the subsequent fall as far as 1840, which was followed by a rise up to 1867, and, finally the fall of 1867–87.

An attempt will now be made to investigate whether the particularly pronounced trends of 1694–1732 (a rise of about 1·4 °C), 1732–1813 (a fall of about 0·8 °C), and 1887–1946 (a rise of about 0·8 °C) in the annual values are reflected in the corresponding monthly values. An answer may be found in Table II, which shows a noteworthy agreement between the monthly values and the relative minimum of the annual values in 1694. Certainly, calculations yield an arithmetic mean of 1690 for the year of

**Table II.** *Comparison of the long-term trends in annual and monthly mean surface air temperatures in central England as derived by applying a Gaussian low-pass filter to suppress all components of fluctuation with $T < 30$ a.*

| | Year of relative min. | max. | $\Delta t$ | Year of relative min. | max. | $\Delta t$ | Year of relative min. | max. | $\Delta t$ |
|---|---|---|---|---|---|---|---|---|---|
| Year | 1694 | 1732 | 9·65 − 8·26 = 1·39 | 1732 | 1813 | 9·65 − 8.83 = 0·82 | 1887 | 1946 | 9·65 − 8·83 = 0·82 |
| January | 1694 | 1734 | 3·77 − 2·13 = 1·64 | 1734 | 1774 | 3·77 − 1·88 = 1·89 | 1890 | 1923 | 4·60 − 3·09 = 1·51 |
| February | 1681 | 1733 | 4·30 − 2·65 = 1·65 | 1733 | 1749 | 4·30 − 3·40 = 0·90 | 1891 | 1917 | 4·48 − 3·62 = 0·86 |
| March | 1695 | 1733 | 5·80 − 4·12 = 1·68 | 1733 | 1785 | 5·80 − 4·53 = 1·27 | 1887 | 1939 | 5·96 − 4·74 = 1·22 |
| April | 1696 | 1732 | 8·40 − 6·74 = 1·66 | 1732 | 1746 | 8·40 − 7·10 = 1·30 | 1886 | 1945 | 8·93 − 7·42 = 1·51 |
| May | 1694 | 1728 | 11·68 − 10·12 = 1·56 | 1728 | 1855 | 11·68 − 10·80 = 0·88 | 1877 | 1917 | 11·80 − 10·52 = 1·28 |
| June | 1695 | 1730 | 14·83 − 13·45 = 1·38 | 1730 | 1814 | 14·83 − 13·93 = 0·90 | 1923 | 1939 | 14·65 − 13·88 = 0·77 |
| July | 1692 | 1780 | 16·48 − 15·31 = 1·17 | 1780 | 1842 | 16·48 − 15·31 = 1·17 | 1888 | 1949 | 16·30 − 15·47 = 0·83 |
| August | 1692 | 1800 | 16·13 − 14·78 = 1·35 | 1800 | 1814 | 16·13 − 15·02 = 1·11 | 1846 | 1938 | 16·40 − 15·09 = 1·31 |
| September | 1692 | 1730 | 14·22 − 12·02 = 2·20 | 1730 | 1838 | 14·22 − 12·78 = 1·44 | 1912 | 1944 | 13·82 − 12·89 = 0·93 |
| October | 1694 | 1730 | 10·04 − 8·64 = 1·40 | 1730 | 1843 | 10·04 − 9·03 = 1·01 | 1889 | 1964 | 10·76 − 8·74 = 2·02 |
| November | 1680 | 1729 | 6·76 − 5·25 = 1·51 | 1729 | 1785 | 6·76 − 5·26 = 1·50 | 1860 | 1946 | 6·84 − 5·26 = 1·58 |
| December | 1676 | 1735 | 4·40 − 2·60 = 1·80 | 1735 | 1799 | 4·40 − 3·13 1·27 | 1885 | 1915 | 4·85 − 3·33 = 1·52 |
| $\overline{Y}$ | 1690 | 1741 | $\overline{\Delta t} = 1·58$ | 1741 | 1804 | $\overline{\Delta t} = 1·22$ | 1886 | 1936 | $\overline{\Delta t} = 1·28$ |
| $s$ | ± 7 | ± 23 | | ± 23 | ± 37 | | ± 20 | ± 15 | |
| $\overline{M}$ | 1694 | 1731 | | 1731 | 1786 1844 | | 1888 | 1934 | |
| $\frac{1}{2}W_c$ | ± 3 | ± 10 | | ± 10 | (± 14)* | | ± 10 | ± 20** | |

*Note.* $\Delta t$ is the temperature difference between the relative minimum and relative maximum, $\overline{Y}$ the mean year of occurrence of the relative monthly extremes, $s$ the standard deviation of the initial years, $\overline{M}$ the mean initial year, referred to the modal class, of the relative monthly extremes, $\frac{1}{2}W_c$ and $1\frac{1}{2}W_c$ the measure of variation, referred to $\overline{M}$, and $\overline{\Delta t}$ the mean of $\Delta t$, referred to the monthly values.

* For a bimodal distribution $\frac{1}{2}W_c$ is unrealistic, and for a uniform distribution it even became necessary to adopt the values $2W_c = \pm 56$.

** $1\frac{1}{2}W_c$ here, because of uniform distribution across 3 classes.

occurrence and a standard deviation of ± 7 a for this year. However, when Sturges's formula (Sachs 1974) is used to divide the years into four classes each having a duration of six years each, namely 1674–79, 1680–85, 1686–91 and 1692–97, the resultant class frequencies are 1, 2, 0, 9.

This distribution differs significantly from a Gaussian normal distribution (it is the so-called *J*-distribution), therefore the given arithmetic mean of all the years must be replaced by the arithmetic mean of the years belonging to the modal class (the class of highest frequency). This mean value is 1694, in agreement with the corresponding year of the annual values. It appears that instead of the standard deviation of all the years of occurrence of the monthly values it is the half-class-width, $\frac{1}{2}W_c = \pm 3$, which should be used as the appropriate measure of variation. If this is interpreted as the range of the values, then 1694 ± 3 embraces the entire modal class.

With reference to the low-pass filtered data, the relative maximum of the annual values observed in 1732 occurs less consistently in the monthly values. On the other hand, however, the frequency distribution of the initial years does differ significantly from a normal Gaussian one, again having class frequencies of 10, 0, 1, 1 and a class width of $W_c = 19$ a. The arithmetic mean for the modal class is the year 1731 ($\frac{1}{2}W_c \approx \pm 10$), only one year before the corresponding year of the annual values.

In relation to the monthly values there is a very inconsistent picture for the relative minimum of the annual values which appeared in 1813, putting an end to the fall in temperature that had taken place after 1732: the mean value occurs in 1804, with a standard deviation of $\pm$ 37 a. The class frequencies are 2, 4, 2, 4 for a class width of 28, and so it is impossible to decide whether it is a case of a bimodal or a uniform distribution. Were it a bimodal distribution the initial years in the two modal classes would be 1786 and 1844 ($\frac{1}{2}W_c = \pm 14$).

The rise in temperature indicated by the low-pass filtered annual values for 1887 to 1946 once again occurs rather more consistently in the monthly trends, but it is in no way as consistent as the rise of 1694–1732. For the relative minimum of the annual values, in 1887, the arithmetic mean of the corresponding monthly data is 1886. If the averaging is carried out solely with reference to the modal class (class frequencies of 2,1,7, 2 for a class width of 20) the result is 1888. These computed initial years differ from one another only slightly. (There are no statistically significant grounds for rejecting the hypothesis that the frequency distribution is normal.)

The most recent relative maximum, which is observed in 1946 with reference to the annual values, occurs between 1915 (December) and 1964 (October) with reference to the monthly values. The frequency distribution of the classes (class width = 13) is 4, 3, 4, 1, that is to say, the distribution is nearly uniform. Taking the first three classes together the mean initial year is 1934. In relation to the classes the measure of variation must here be taken as $1\frac{1}{2}W_c = \pm 20$.

An example of the inconsistency of precisely this most recent rise in temperature may be seen in the fact that the June values have a minimum, which otherwise occurred on average in 1886–88, during 1923, while in the same year the January values have already reached the relative maximum of the first half of the twentieth century.

Rocznik (1972) investigated the seasonal mean temperature at De Bilt, Potsdam, Vienna and Basel, using (non-running) 10-year means, and equally found significant seasonal differences; at these places the winter temperatures reach their maximum in the decade from 1911 to 1920, and this is in good agreement with the mean of the corresponding years of occurrence in central England for December (1915), January (1923) and February (1917). Rocznik found, however, that the spring, summer and annual values consistently exhibit their relative maximum in the decade from 1941 to 1950, while the autumn values do not peak until 1961–70. This last result coincides with the finding of the present paper for October, namely a relative maximum as late as 1964.

Comparison of the annual trends with those of individual months shows, therefore, that these data show very different variability patterns in the individual climatic epochs. For this reason it is unreliable to use investigations of the rise in temperature during the first half of the 20th century, for example, to draw conclusions having claim to general validity. The most recent relative maximum is itself particularly inconsistent concerning the way in which it occurs in the individual months. As pointed out, a counter example is the relative minimum of 1694 $\pm$ 3.

The results in question will now be related to the zero-dimensional climatic model of Schneider and Mass (1975). This model employs the relative sunspot numbers and the indices of concentration of volcanic dust in the atmosphere (Lamb 1970) as contributory factors. A prominent minimum of the global mean surface temperature occurs in the period from 1670 to 1700, with a much less clearly marked minimum from 1810 to 1830. Both minima may be verified by the analysis here described, as

far as the qualitative relation is considered. For this reason the first-mentioned relative minimum, in particular, but also the subsequent rise in temperature, could be traced back to external influences.

As to the rise in temperature during the first half of the twentieth century, the climatic model of Schneider and Mass does not exhibit a prominent relative maximum, nor does the present analysis of monthly values show a satisfactory consistency in the timing of extremes. It therefore seems that external factors come into the question either on a smaller scale, or even not at all. This holds, equally, for the much-discussed humanly generated influence leading to a rise in temperature through the production of $CO_2$, the more so since at present there seems again to be a prevailing drop in temperature. Global considerations, too, show no signs at present of a steady turn-around in the cooling trend (Angell and Korshover 1977; Kukla *et al.* 1977; Schönwiese 1978d).

**Comparison of the variance spectra**

The temperature series for central England will now be used to examine the spectral distribution of the variance throughout the entire accessible range of periods $T > 1$ a, making comparison between the annual means and the corresponding monthly means. Figure 2 shows the selected examples of the variance spectra, while Table III gives an exhaustive list of the periods connected with relatively high variance. Note that the values keep within narrow intervals for shorter periodicities, while for increasing periods the scatter becomes larger. Thus, for a period of '2·2 a' the accuracy is *c.* $\pm$ 0·05 a; for '5·1 a' *c.* $\pm$ 0·2 a; for '25 a' *c.* $\pm$ 4 a; and for '100 a' only 60–200 a.

Consequently, in connection with the variance maxima arising between 67 a and 200 a it is necessary to refer to the analysis of the longer palaeoclimatological series. As an example, Dansgaard *et al.* (1970) found variance maxima at *c.* 80 a and *c.* 180 a by analysing a temperature series for Greenland based on estimates derived with an oxygen isotope method applied to an ice-core sample (for a review of palaeo- and neo-climatological methods and results see US Committee for the GARP, 1975). In this range of periods the variance spectrum of the relative sunspot numbers also possesses a particularly significant maximum (Schönwiese 1978a).

The remaining monthly maxima are grouped, also in a very varied fashion, around the following period intervals:

22–33 a (March to May are very significant, August to February are missing);
9–15 a (mostly of low significance or missing);
4·5–8 a (accumulation around 5 a, but mostly of low significance or missing);
2·9–3·9 a (very varied, 2·9–3·6 a partly very significant, however); and
2·1–2·8 a (2·2–2·4 a, in particular, is frequent and very significant).

The quasi-biennial oscillation which has been very frequently observed, but whose causes remain unexplained, (for a summary see, for example, Kriester 1964; Landsberg 1962; Schönwiese 1969, 1974) is particularly well supported in statistical terms by the present investigation. As to the range of periods $T > 50$ a, it is necessary to await further palaeoclimatological analyses, which will allow a better determination of the variance maxima arising.

The component of fluctuation which seems to correspond to the double sunspot cycle (the so-called Hale cycle (Dreier 1977)) is certainly less clearly in evidence than the two variance maxima of the quasi-biennial and of the relatively prolonged ($T > 50$ a) periods but is to be seen in the spectrum of annual values. The same holds true of the fluctuation component which according to Baur (1949) represents a double wave within the sunspot cycle (although the interpretation is very questionable, cf. for example Schönwiese 1976), and especially of the component with periods of around 3 a, which remains to be considered.

**Table III.** *Relative maxima of the variance spectra of annual and monthly means, based on surface air temperature in central England,* 1660–1969.

| Year | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 200(> 95) | 200(> 80) | 200(> 80) | | | | | | | | | |
| 100(> 95) | | | | 67(> 80) | | 67(> 90) | | 100(> 80) | 100(> 95) | 100(> 90) | 67(> 95) | 100(> 90) |
| | | | | | | | | 33(> 80) | | | | |
| 25(> 80) | | | 22(> 90) | 25(> 90) | 22(> 90) | 25(> 80) | 25(> 95) | | | | | |
| | | | | | | | 15(> 80) | | | | | 15(> 80) |
| [14(> 80)] | | 12(> 80) | 13(> 80) | | | | | 14(> 80) | | | | |
| | | 9·1(> 80) | 10(> 80) | 10(> 80) | | 10(> 80) | 10(> 80) | | 10(> 90) | | | 12(> 80) |
| | 7·7(> 80) | | 7·7(> 80) | | | | | | | | | |
| [7·4(> 80)] | | | | | | | | | | 7·4(> 80) | | |
| | | 6·9(> 80) | | | 6·9(> 80) | | | | | | | |
| | | | 6·1(> 80) | | | | | | | | | |
| 5·1(> 80) | | 5·1(> 80) | | | 5·3(> 80) | | | 5·4(> 80) | 5·3(> 80) | | 5·7(> 80) | |
| | | | | | | 5·0(> 80) | | | 5·0(> 80) | | | 5·1(> 80) |
| | | | | | | | | | | | 4·5(> 80) | |
| | | | | | | 3·8(> 90) | | | | 3·9(> 80) | | |
| 3·4(> 80) | 3·5(> 80) | | | | 3·7(> 90) | | | | 3·7(> 80) | | 3·6(> 95) | 3·8(> 80) |
| | | | | | | 3·3(> 80) | 3·4(> 80) | | 3·4(> 80) | | | 3·4(> 80) |
| | | | | | | 3·2(> 80) | | | | | | |
| 3·1(> 90) | 3·1(> 95) | | 3·0(> 90) | | | | | | | 3·0(> 90) | | |
| | 2·9(> 90) | 2·9(> 90) | | | | | | 2·9(> 90) | | | | 2·8(> 80) |
| | 2·6(> 80) | | 2·6(> 80) | | | | | | | | | |
| | 2·3(> 80) | 2·3(> 90) | | 2·4(> 80) | | 2·5(> 80) | 2·5(> 80) | 2·4(> 90) | 2·5(> 80) | 2·5(> 80) | | |
| 2·2(> 95) | 2·2(> 95) | 2·2(> 90) | | 2·2(> 95) | 2·2(> 80) | 2·2(> 90) | 2·2(> 95) | | | 2·3(> 90) | 2·2(> 90) | |
| | 2·1(> 80) | | 2·1(> 80) | | | | | | 2·1(> 80) | | | |
| *W** 24 | 252 | 221 | 134 | 93 | 85 | 76 | 78 | 71 | 79 | 103 | 113 | 181 |
| *A* 0·27 | 0·03 | −0·02 | 0·06 | 0·17 | 0·16 | −0·03 | −0·02 | 0·12 | 0·15 | 0·10 | 0·10 | 0·05 |

* in $10^8$ $K^2/\Delta f$

*Note.* Unbracketed numbers give the mean period of the maxima in years, bracketed numbers their significance in per cent, as determined by the $\chi^2$ test. In addition, the table also contains the variance of the 'white' spectrum $W$ and the first-lag autocorrelation coefficient $A$.

In connection with the question of what causes the given prevailing components of variance no point of view will be expressed here beyond Lamb 1972, 1977; Mitchell 1976; Schönwiese 1969, 1974. However, it must be mentioned that the given periods of the prevailing variance components continue to come to light in many investigations, cf. for example Baur, 1949; Dehsara and Cehak 1970; Fleer 1975; Kortüm 1974; Kriester 1964; Landsberg 1962; Landsberg and Kaylor 1976; Markham 1974; Polli 1946; Schönwiese 1969, 1974, 1976, 1978a, 1978c. A synopsis of the statistical structures outlined here seems to bring up the question of external influences, or at least of non-stochastic processes, with reference above all to the range of periods $T > 50$ a, but also to the quasi-biennal cycle. Otherwise, the results seem to point to internal processes in the climatic system and in the general circulation of the atmosphere, though it is true that the details of the connection remain unclear.

It also remains unclear why the autocorrelation coefficients between months following one another at a distance of one year point partly to 'white' spectra without persistence and partly to 'red' spectra with persistence (Mitchell 1966, Panofsky and Brier 1958). The highest autocorrelation coefficient occurs in connection with the annual values.

The variance integrated over the entire interval of periods $T > 1$ a, which can be obtained by computing the appropriate 'white' spectra, has highest values in the winter half-year (maximum in January), and lowest values in the summer half-year (minimum in August). Again, this may be the result of feedback processes, in conjunction with the snow cover.

Taken overall, the variance of the monthly mean spectra is much greater than that of the annual spectrum. This means that many of the fluctuations must be of a 'compensating' nature, that is to say, they cancel each other out in relation to the annual variability. In conjunction with Table I this is a further indication that the connection between the monthly and annual values is not particularly good. As already mentioned, the relationships are more favourable in the range of periods $T > 30$ a or $T > 50$ a.

A great deal of statistical work is still required, however, to build up a picture, station by station and in neo- and palaeo-climatological outline, of the fundamental characteristics of fluctuation of all the important quantities of the climatic system. The present paper can do no more than make a very small contribution in this direction.

**Acknowledgement**

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# Offshore wind energy systems*

By P. J. Musgrove

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**Summary**

It is shown that arrays of windmills deployed in the shallow waters of the southern North Sea could produce 20 per cent of the electricity needs of the United Kingdom. Costings based on 1976 prices show that wind-generated electricity is already competitive with that from oil- and coal-fired power stations.

## Introduction

Wind energy systems deployed in the shallow but windy waters of the southern North Sea have the potential to provide more than 20 per cent of UK electricity needs. With existing experience of windmills, and of aircraft and offshore structures, such wind energy systems could be developed within a relatively short time-scale. A preliminary assessment of the economics of offshore wind energy systems is encouraging, and if action is taken soon we could deploy windmills offshore in large numbers by the late 1980s. Energy from the wind would then be available soon after the worldwide demand for oil is predicted to exceed the maximum available supply, with all the implications that this has for the price of fossil fuels.

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* Previously published in *Physics Education*, **13**, 1978, 210–214.

Before considering offshore wind energy systems in more detail, the limits to the potential of windmills on land are worth review. The power output from a windmill is proportional to the cube of the wind speed, and for low-cost energy production, windmills must consequently be located in areas of high mean wind speed. On land this requires windmills to be sited on hilltops, and in the 1950s the Electrical Research Association surveyed and selected about 1500 suitable hilltop sites, having mean wind speeds at the summit of about 9 m $s^{-1}$. Unfortunately most of these locations (*c.* 1100) are in Scotland, remote from the main centres of power consumption in the Midlands and the South, and outside the areas served by the Central Electricity Generating Board (CEGB). About 1000 MW of wind generation capacity could, in principle, be installed on the remaining sites in England and Wales, since on average windmills rated at two or three megawatts could be installed on each summit. However, most of these hilltop locations are in National Parks or other areas of outstanding natural beauty, and there would undoubtedly be strong environmental objections to siting large numbers of windmills in such locations. And it must be remembered that the visual impact is not confined to the windmills on each summit, but includes the access road up to the summit and the overhead power lines running from the summit to the nearest suitable grid connection, which may well be 20 km away.

The maximum wind generation capacity, in England and Wales, of about 1000 MW corresponds to about 1·7 per cent of the installed capacity of the CEGB. However, environmental objections could in practice limit the installed wind-generation capacity to well below 1 per cent of the CEGB'S total capacity. It is doubtful whether so small a contribution from windmills on land could justify a national wind-energy program to develop the required megawatt-rated windmills.

**Offshore windmills**

The potential contribution from windmills offshore is, however, at least an order of magnitude greater. There is a very large area of windy and relatively shallow water around the coast of the United Kingdom, and the area of the southern North Sea looks particularly attractive, both because it is so shallow and because windmills in this area would be close to the main centres of power demand. Figure 1 shows the very extensive shallow-water area off the Wash. In order to avoid relatively low wind speeds near the coast, and to minimize visual impact, windmills should be deployed at least 10 km offshore. The cost of transmitting power to the shore—about £50/kW for a distance of about 30 km (Denton *et al.* 1975)—provides an incentive not to go too far offshore, but between 10 and 50 km from the shore the area of shallow water off the Wash having a depth less than 20 m exceeds 4000 $km^2$.

Figure 2 shows a scaled-up version of the Reading variable-geometry vertical-axis windmill design as it might appear in shallow offshore waters, with the tower extending down to and into the sea bed. Meteorological Office data* for the offshore area of Figure 1 indicate that the distribution of the duration of wind speed is identical to that shown in Figure 3, and the annual mean speed—at the standard height of 10 m above sea level—is 7·2 m $s^{-1}$. However, the wind speed increases with height above the surface; this variation is usually expressed in the form

$$V_m = cH^{\alpha},$$

where $V_m$ is the mean wind speed, $c$ is a constant, $H$ is the height, and the exponent $\alpha$ is a parameter whose value depends on the roughness of the terrain (see for example Ljungstrom 1976). Over smooth inland areas $\alpha$ has a value of about 0·30, but for coastal and offshore areas this becomes 0·14. Consequently at the hub height of a multimegawatt offshore windmill, some 50 m above sea level, the annual

* Provided by Met 0 3c, Meteorological Office, Bracknell, for light-vessel Dowsing (53° 34′ N, 00° 50′E) and separately for sea area 52–54°N, 0–2°E.

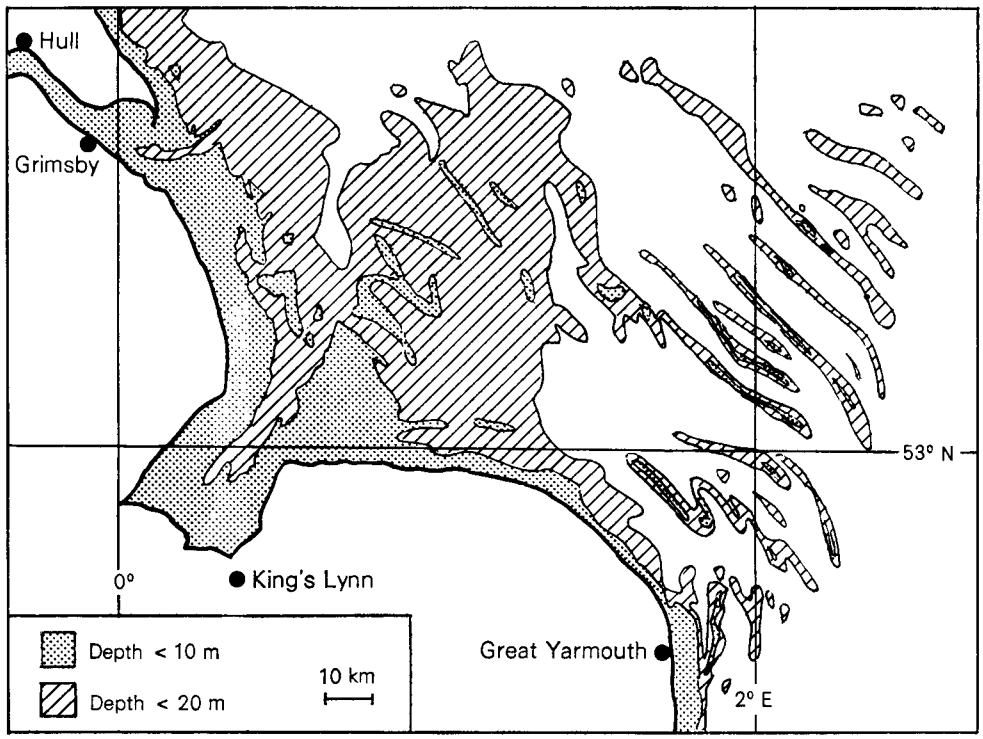


Figure 1. Shallow waters off the Wash.

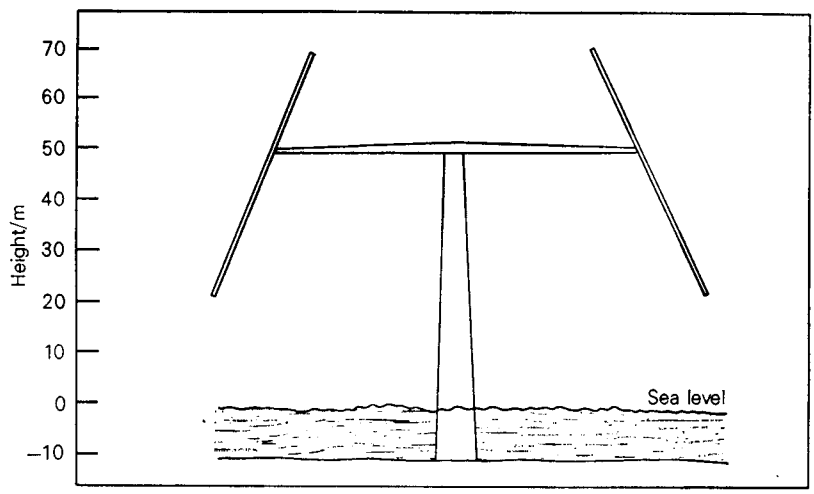


Figure 2. Schematic diagram of a windmill rated at 2·5 MW and having a diameter at hub height of 70 m.

mean wind speed will be $(50/10)^{0.14} = 1{\cdot}25$ times the annual mean wind speed at 10 m. For $V_m = 7{\cdot}2$ m s$^{-1}$ at 10 m one therefore has $V_m = 9{\cdot}0$ m s$^{-1}$ at 50 m, the height of the rotor centre. As stated previously, the power in the wind is proportional to the cube of the wind speed; cubing the ordinates of Figure 3 and then averaging therefore allows one to calculate the average power in the wind. It can be shown (Department of Energy 1977) that the annual average wind power is equal to $2{\cdot}4 \times (\frac{1}{2}\rho V_m^3)$, where $\rho$ is the air density and $\frac{1}{2}\rho V_m^3$ is the power in the wind at the annual mean wind speed. A mean wind speed of 9·0 m s$^{-1}$ consequently corresponds to an average wind power density of 1100 W m$^{-2}$.

The 70 m diameter windmill shown schematically in Figure 2 has a rated power output of about 2·5 MW in a 13·5 m s$^{-1}$ wind (1·5 × average wind speed) and will give an annual load factor of about 40 per cent (that is to say, the annual average power output will be 1 MW). One of the attractions of wind energy is the fact that wind speeds are higher in winter than in summer, and the seasonal availability of wind energy closely matches the seasonal variation in electricity demand. The average power output from a windmill (and hence its load factor) is consequently significantly higher in winter than in summer. Of course, a conventional horizontal-axis windmill, such as that shown in Plate I, could be used offshore instead of the more novel vertical-axis windmill shown in Figure 2. For the same rated power output it would have a similar diameter.

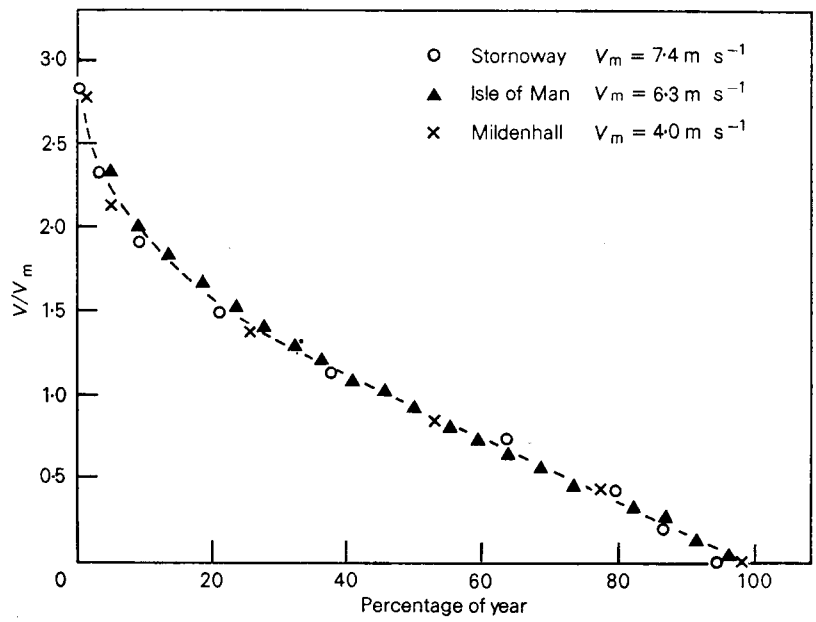


Figure 3. Distribution of duration of wind speed.

## Windmill clusters

To facilitate supervision and maintenance, and to minimize the cost of interconnecting the power outputs from individual windmills, offshore windmills should be deployed in clusters of about 1000 MW total installed capacity. A windmill cluster based on the 2·5 MW design outlined in Figure 2 would therefore consist of about 400 windmills. Golding (1976) suggests that the distance between large

*To face page 116*

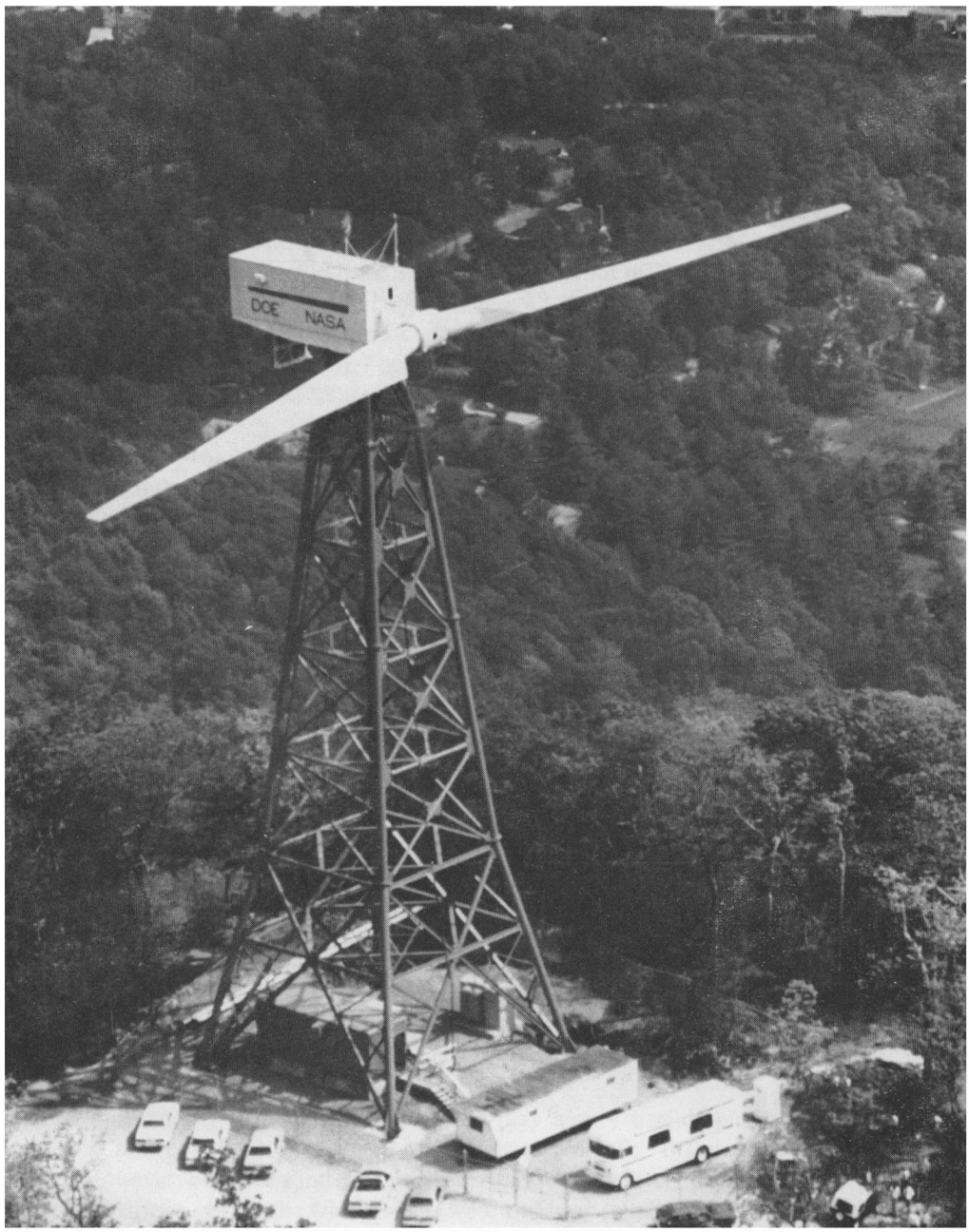


Plate I. Two-hundred foot diameter wind turbine rated at 2 MW. Completed in summer 1979 at Boone, North Carolina. Constructors General Electric Co. Blades by Boeing Engineering and Construction.

windmills should be about eight diameters, and recent Swedish studies (Ljungstrom 1976) suggest a spacing of about seven diameters. The distance between 70 m diameter windmills should therefore be about 0·5 km. A 400 windmill cluster, in its simplest form, would then be a 20 × 20 grid occupying an area of 10 km × 10 km (easily visualized on Figure 1). In practice the shape of the cluster would be modified to take advantage of sea-bed contours and the fact that some wind directions occur more frequently than others. If an inter-windmill spacing of ten diameters were considered more appropriate (there is still some uncertainty about the optimum spacing between windmills in a cluster) the 400 windmill cluster would require an area of 14 km × 14 km, which is less than five per cent of the total hatched area shown in Figure 1.

One such windmill cluster would have a rated power output of 1000 MW and give an average power output of 400 MW. These figures are comparable with the output of conventional (oil- or coal-fired) power stations on land*. One windmill cluster would provide 1·7 per cent of our annual electricity needs, equivalent to approximately 1·7 million tons of coal, or 1·0 million tons of oil, per annum. In the area off the Wash one could locate several such windmill clusters, and other locations around our coasts, for example Cardigan Bay, could provide additional shallow-water sites for offshore windmill clusters. The total wind power potential, for clusters sited in water no more than 20 m deep, is approximately 20 per cent of our present electricity requirements, and if it proves economic to deploy windmills in rather deeper water, for example up to 30 m deep, this potential can be doubled.

Wind energy systems therefore have the potential to provide a significant proportion of our electricity requirements, and their environmental impact is minimal. However, it must be recognized that wind energy systems do not provide a firm power output unless they are associated with large-scale energy storage systems, for instance surface or underground hydroelectric energy storage. Although such storage schemes are at present under development in the United States of America, their costs are still uncertain. Initially at least, the development of offshore wind energy systems must be justified by their use without any energy storage.

Windmills without energy storage provide an output on an intermittent basis, which would allow some of the least efficient fossil-fuelled power stations to be shut down on windy days, so saving oil or coal. The amount of intermittent wind generation capacity that can be connected to the grid system is about 12 000 MW. This represents about five thousand 2·5 MW windmills within the United Kingdom, and the export potential, in Europe and elsewhere, is even greater. Even without energy storage 120 000 MW of UK wind generation capacity would provide about 20 per cent of our electricity needs and save approximately 12 million tons of oil annually. Moreover, calculation of the energy recovery period for large windmills indicates that the energy consumed in their manufacture is recovered well within the first year of their operation.

## Cost of wind energy

Offshore wind energy systems could therefore play a very useful role in meeting Britain's future energy needs, and could also provide a major new activity for Britain's aerospace and engineering industries. However, offshore wind energy systems will only be introduced if they can provide electricity at a competitive price. Since the wind itself is free, and is an inexhaustible source of energy, the cost of wind-generated electricity is dominated by the amortization of the windmill system's capital cost.

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* The 59 000 MW net capacity of the CEGB is provided by 161 power stations and the overall load factor for 1975–76 was 40 per cent. The 20 most efficient fossil-fuelled stations have a net capacity of 26 000 MW and their load factor for 1975–76 was 54 per cent (CEGB 1977).

Since no manufacturer has yet developed a multimegawatt windmill for production in quantity, the capital costs are not known with any precision. However, recent detailed cost studies (Coty and Vaughn 1977, Coty and Dubey 1976) by Lockheed in the USA indicate that the construction and installation on land of a 2 MW rated, 80 m diameter, horizontal-axis windmill would cost \$500/kW if produced in quantity (that is to say, several hundred units). The Lockheed figures relate to a two-bladed variable-pitch design and a rated wind speed of 12 m $s^{-1}$ at hub height. The studies also indicate that if the annual mean wind speed at hub height is 9 m $s^{-1}$ (corresponding to conditions that offshore windmills in the southern North Sea would experience) the design would give a load factor of 47 per cent. Similar detailed studies by General Electric and Kaman Aerospace (*Proc. Second Workshop on Wind Energy Conversion Systems* 1975, *Proc. Vertical Axis Wind Turbine Technology Workshop* 1976) have produced similar conclusions and cost predictions, and General Electric was subsequently (late 1976) awarded a contract to build its 2 MW windmill design, which was completed in 1979.

At the current exchange rate of £1 ≈ \$2, the windmill cost of \$500/kW corresponds to £250/kW. This includes approximately £50/kW for the tower cost, on land. In an offshore location the tower cost would be substantially increased, and initial estimates suggest that the extra cost of offshore towers would be about £100/kW. Transmission to the shore of the windmill cluster's 1000 MW rated power output would add a further £50/kW and the total cost of an offshore wind energy system is therefore expected to be about £400/kW, at 1976 prices. The cost per windmill of an offshore windmill cluster would therefore be approximately £1 million, with the tower cost contributing £0·4 million per windmill.

If one assumes a 10 per cent charge rate on the required capital investment of £400/kW (Coty and Vaughn (1977) discuss the range of charge rates that could be applicable in differing circumstances) then the cost of wind-generated electricity is 1·2 p/(kW h) (or 0·33 p/MJ). This is somewhat higher than the average cost per kilowatt hour of the fuel burnt in oil- and coal-fired power stations, which for 1975–76 was 1·02 p/(kW h) (0·28 p/MJ). However, most wind energy is provided in the winter months, when power stations low in the merit order have to be operated, and the fuel saving value of wind-generated electricity is more nearly 1·2 p/(kW h) (0·33 p/MJ). Based on these figures* wind-generated electricity is already competitive with the fuel cost of electricity generated in fossil-fuelled power stations. If one were confident that oil prices would in future remain stable, in real-money terms, and that oil would continue to be available, there would be little incentive to develop wind energy systems, or indeed any other alternative energy systems. However, the Organization for Economic Co-operation and Development (OECD) predicts that the demand for oil will exceed the maximum available supply in the mid-1980s, and recent American studies commissioned by President Carter suggest that the mismatch between supply and demand may occur as soon as 1983. Moreover this world-wide oil shortage will not be a temporary phenomenon, but will become progressively more acute. One can therefore be certain that oil prices, and consequently the price of other fossil fuels, will rise very significantly in real-money terms in the 1980s. What is uncertain is the precise magnitude and timing of these increased prices. However, it will take nearly a decade to develop large wind energy systems to the stage where they can be deployed offshore and make a useful contribution to Britain's energy needs. The necessary development program should consequently be initiated as soon as possible.

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* Alternatively one may argue that since a 1000 MW offshore windmill cluster would provide an electricity output equivalent to 1 million tons of oil per annum the break-even oil price is £41/ton, that is to say that wind-generated electricity will be economic when the price of oil to the power station exceeds £41/ton. The price of crude oil still continues to rise, and at the time of going to the press (January 1980) was from \$24 to \$32 or more per barrel, i.e. at least £75 per ton.

Fortunately wind energy systems can be developed step by step at relatively low cost. Only after a particular windmill design has been tried and proven and shown to produce electricity economically would one incur the cost of deploying large numbers of windmills offshore.

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## Sixty years ago*

*Weather Insurance.* The weather is a very important factor in all outdoor occupations and amusements, and the losses involved when adverse weather conditions are experienced amount annually to very large sums. One has only to consider a few instances, such as a promising hay harvest spoilt by rain, corn crops partially ruined by hail storms, building contracts held up by frost, cricket and football matches, and race meetings abandoned owing to frost, snow or rain, to see that the question of Weather Insurance is of great importance.

In the past a certain amount of insurance has been effected against such risks, but the premiums have often been prohibitive, owing to the fact that they were based on a small volume of business and that no reliable data of the average weather conditions had been collated.

The Eagle, Star and British Dominions Insurance Company, Limited, has now, however, opened a special Department, named the 'Pluvius' Department for operating in Weather Insurance, and various forms of policies have been prepared, covering as far as possible all insurable weather risks, including the provision of compensation to holiday-makers in the event of excessive rainfall during the insured period. It is anticipated that there will be a large and growing demand for this kind of insurance.

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[The Eagle, Star and British Dominions Insurance Company was the first company to co-operate with the Office on insurance against rainfall and the first to develop a proper actuarial system for assessing the financial risk.]

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* *Meteorol Mag*, **55**, 1920, 50.

## REVIEWS

*The yachtsman's weather guide*, by Ingrid Holford. 215 mm × 135 mm, pp. 88, *illus.* Ward Lock Limited, London, 1979. Price £3.95 hardback, £1.95 paperback.

This book is generally good on synoptic-scale meteorology and there is a wealth of useful practical advice born of experience. Rather more than half is devoted to chapters on synoptic charts, winds associated with low- and high-pressure systems, and how to make the best practical use of all the information which is available from shipping bulletins and personal observation. Some of these sections are excellent with occasional masterpieces of prose expressing an understanding and appreciation of the behaviour of weather and weather systems of which any professional meteorologist would be proud.

Much of the early chapters is devoted to local winds, sea-breezes, convection, and developing some simple physical ideas about heat and water vapour. Here there is a great variation in quality. Some parts, such as those on atmospheric pressure and cumulus clouds are good, and the author has conceived some novel and useful illustrations to explain things like saturation. But some other attempts at loose descriptions of physical concepts are likely only to mislead.

The weakest paragraphs are those dealing with gusts, winds associated with cumulus and cumulonimbus, and sea-breezes. The author does not distinguish between the airflow in raining and non-raining cumulus, and the diagram of winds near a cumulonimbus (page 45) is wrong. The sea-breeze is not 'dependent on unobscured and strong sunshine'. Weak diffuse sunshine through thin stratocumulus can cause enough warming to produce a good sea-breeze so long as the orientation of the gradient wind to the coast is favourable. The space occupied by largely unnecessary diagrams on pages 56 and 59 would have been much better employed in telling the yachtsmen how and when the sea-breeze is likely to develop offshore.

With the 1979 Fastnet race still very much in mind I looked up 'gale' in the index and found the subject well covered. Definitions of winds include the important reference to gusts: 'gale' being Force 8 with gusts to Force 9, and 'storm', Force 10 gusting to 11. Attention is drawn to the rate of fall of pressure heralding strong winds and to the synoptic situations which often produce gales.

One aspect of gustiness which I have not seen handled in any other book is the so-called 'weight of wind'. The author provides a good explanation of this phenomenon which many yachtsmen have regarded as a mystery. But I am not sure that she is right to dismiss completely the influence of air density.

All in all this is a useful book and good value. The author should be proud of her effort, so it is a pity she does not identify herself in the photograph on page 35.

D. M. Houghton

*Buoyancy effects in fluids*, by J. S. Turner. 215 mm × 140 mm, pp. xv + 368, *illus.* Cambridge University Press, London, 1979. Price £7.95 paperback, also available in hard covers.

In this book, which is written with the needs of both undergraduate and postgraduate students in mind, Professor Turner seeks to explain a range of phenomena which arise in fluids in which there exist (small) density variations. While he has confined his attention to flows in which rotation is not important, the author has included many topics which will be of interest to the meteorologist or oceanographer as well as several which have engineering applications.

Following a brief introductory chapter in which the basic ideas are explained, there are chapters describing linear internal waves, finite amplitude phenomena in stratified fluids and instabilities of shear flows in stratified fluids. A separate chapter is devoted to a discussion of turbulent shear flows. Two following chapters consider the problems of buoyant convection from isolated sources and convection from heated surfaces. The final chapters discuss double diffusive phenomena, mixing across density interfaces and various internal mixing processes. The chapters are each largely self-contained but where the subject requires knowledge of material in other chapters, adequate cross-references are given.

The subjects included necessarily require some mathematical analysis but the author discusses the physical principles involved so that the material should be accessible to a student with a limited mathematical background; some familiarity with the dynamics of homogeneous fluids is however required. Throughout the book a good balance has been achieved between the theoretical ideas and the observations in the laboratory, in the atmosphere and in the oceans. The text is complemented by clear diagrams and many excellent photographs although the insertion of the plates in one place makes reference to them a little inconvenient.

A topic which the reviewer found of particular interest was the development of thermal convection from isolated sources. The treatment, which is typical of that in the other chapters, includes a clear discussion of the development of theoretical ideas which in this case consists of the use of similarity solutions and the assumptions which can be made to treat different situations. This is followed by discussion of other flows in which similar ideas can be used and descriptions of laboratory experiments in which the theoretical ideas may be tested. There are some omissions, in this case the effects of conditional instability which may affect the development of buoyant plumes in the atmosphere, but these do not generally detract from the aim of the book which is to explain the basic ideas.

The material included in the book is rather dated, it being a reprint of a volume first published in 1973, for although some errors have been corrected there has been no updating of the text. This may reduce the usefulness of the book to research workers requiring background material to topics related to their speciality although an updated list of references helps to bridge this gap. The basic principles introduced in this book have not, however, changed and for this reason the book will remain an excellent textbook for teaching purposes; the appearance of this paperback edition will make it accessible to many more students.

P. R. Jonas

*Causes of climate*, by J. G. Lockwood. 240 mm × 150 mm, pp. x + 260, *illus.* Edward Arnold, London, 1979. Price £12.95 (boards), £5.95 (paperback).

This book was written for first and second year university students in geography and environmental sciences. It therefore requires no higher mathematical skills of the reader. The author's desire for a thorough, complete treatment has led to some repetitiveness and tautology, for instance part of page 6 is repeated on page 21, and on page 200 we find 'In many ways drought is the hydrological opposite to flooding'.

After an introductory chapter in which the general climatic system and its elements are defined in a highly condensed but correct discourse, the basic facts about radiation are provided, followed by an instructive chapter on interactions between the atmosphere and the underlying surface, including a mention of Budyko–Sellers global climate models. The following chapter on the atmospheric circulation also includes subsections on the distribution of radiation and on the hydrological cycle. Climatic change and glacial periods are introduced by a slightly unclear description of Lorenz's concept of

'almost-intransitivity', but the rest of the chapter summarizes present knowledge (or opinions) well. Some of the statistics (e.g. Tables 5·2–5·5) show unwarranted precision (though they are all quotations from other authors).

The consequences of climatic change are discussed in Chapter 6 in terms of hydrology illustrated by a hydrological model (hence the expression 'climatic model' in the title: there is no reference here to a global dynamical or radiative model). There is a concise final section on man-made influences on local and global climate. The last chapter is wisely cautious about future climate.

A few mis-statements need correcting. There are not always westerly winds in the stratosphere (p. 36). Blocking patterns have a wide spectrum of lifetimes (p. 131). The correlation between ice cover and insolation is not close in Figure 5.11 (p. 165). The $CO_2$ concentrations at Barrow and in Scandinavia do not appear in Figure 6.19 to exceed those at Mauna Loa (p. 221). Kondratyev and Nikolsky no longer hold to their sunspot versus solar-constant formula (p. 224, p. 26). There are also a few serious misprints; in Figure 4.21 'subpolar flow' should read 'subpolar low' (twice). On pages 101 and 191 west(ern) should read east(ern). On page 126, 600 m should read 600 km. These and some other errors could mislead the uninitiated. However, these apart, the book is well suited to its intended readers.

D. E. Parker

*The climate mandate*, by W. O. Roberts and H. Lansford. 225 mm × 165 mm, pp. viii + 197, *illus.* W. H. Freeman & Company Ltd, Reading, 1979. Price £6.70 (hard cover), £3.30 (soft cover).

The authors—one a journalist and one a meteorologist—present a convincing case for the importance of climate and of our understanding of climate and its economic impacts in relation to world food supplies.

Although the book is intended for the general reader, it is largely free of the unjustifiable extreme statements which are common in popular writings on climatic change. Past and present climate, and natural and man-made causal mechanisms are described in an appropriately cautious manner, although the reviewer is not as convinced as the authors about some of the solar–terrestrial influences (p. 77). Seasonal and longer-range forecasting techniques are described in clear terms for the layman.

An entire chapter devoted to recent economic history illustrates the complex links between crops, climate, and social and political factors. Following from this, attempts to modify the weather, by cloud seeding, and to modify crops, by genetic breeding, are described in Chapter 7. The results of cloud seeding are correctly shown to be generally ambiguous. Finally an economic attitude is proposed which synthesizes the views of Malthusian pessimists (who fear the results of overpopulation), social idealists (who believe in Utopia via new social and political structures) and technological optimists. The authors admit that their proposals would involve self-sacrifice on the part of some richer nations, and therefore human nature is what will make their suggestions stand or fall.

There are a few slips. On page 28, $10^{-1}$ year is described as one year instead of 1/10 year. There was snow in south Florida in 1975 (page 83). On page 96 the British GATE ships are omitted, and a non-existent one from East Germany included (the authors used an old GATE plan which was superseded).

The book is a useful guide for those without technical, meteorological or economic background.

D. E. Parker

## Honour

We note with great pleasure that in the 1980 New Year Honours List a British Empire Medal was awarded to Miss Mary K. Rope of Leiston, Suffolk, who has sent rainfall readings first to the British Rainfall Organization and then to the Meteorological Office since January 1909.

## Notes and news

### Appointment of new Secretary, Meteorological Office

Mr Frederick Raymond Howell, M.B.E. (Military), F.C.I.S., has been appointed Secretary, Meteorological Office as from 7 January 1980 to succeed Mr A. C. Hughes. Mr Howell trained as an electronic engineer, and from 1940 to 1967 served in the Royal Engineers as a Regular Army Officer, attaining the rank of Colonel; while in the Army he held both regimental and staff appointments. From 1967 to 1970 he was Principal Officer, Plans and Administration, with Surrey County Council, and then joined the Civil Service as a Principal in the Air Force Department. In 1974 he was promoted to Assistant Secretary in the Navy Department as Head of Naval Personnel Division 2. In his younger days he was a keen Rugby footballer, both as player and referee, played cricket, and sailed. All Meteorological Office staff will wish him well in his new appointment.

### Successful completion of the data collection phase of the Global Weather Experiment

The operational year of the Global Weather Experiment ended on 30 November 1979. During that year, which comprised the data collection phase of the Experiment, the most comprehensive and modern observing techniques and data collection systems ever used enabled the 150 Members of WMO to keep the whole atmosphere and the ocean surface under constant surveillance. The Global Weather Experiment, also called FGGE*, is a major component of the Global Atmospheric Research Program (GARP). The aims of the Experiment are to gain a better understanding of atmospheric motions for the development of more realistic models for weather prediction and to assess the ultimate limit of predictability of weather systems. A closely related aim is to design an optimum composite meteorological observing system for the future. It is also hoped, within the limitations of the one-year period of observations, to investigate the mechanisms underlying fluctuations of climate.

The next step in the Experiment is to complete the collection and quality control of the enormous mass of observational data and to organize it in coherent sets in a form directly usable for research. This work is already in progress and in about two years the full data sets will be archived in the world data centres in Moscow and Washington and will be made available to all research institutes which need them. Research work using some of the data, which has already begun during the operational year, is expected to continue up to 1985 at least.

While it is not possible at this stage to draw any scientific conclusions from this Experiment, the first assessment made by the FGGE Inter-Governmental Panel which met in Geneva in November 1979 indicates that the observational phase has been carried out very successfully.

Virtually all 150 members of WMO participated actively in the data collection phase, during which the atmosphere was observed more intensively than ever before. The participating countries took special measures to augment their routine data collection activities and several special observing systems were implemented during two Special Observing Periods (January–February and May–June 1979) to provide atmospheric and oceanographic observations from data-sparse areas.

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* FGGE is the acronym for First GARP (Global Atmospheric Research Program) Global Experiment. (See *Meteorol Mag*, 1979, **108**, 129–134.)

Examples of new observing techniques which were deployed for the Experiment are third-generation polar-orbiting satellites, ocean data buoys, constant-level balloons, special instrumentation for commercial and research aircraft, and special techniques for atmospheric sounding from ships. The performance of these systems exceeded the expectations of the planners of the Experiment, and it is therefore envisaged that it will be possible to use these systems in the future for an improved global weather observing system.

The first assessment which has just been made indicates that the observational requirements stated for the Experiment were met to a large extent and even exceeded in certain areas. The data sets now being processed and assembled into the final format will be the most extensive meteorological data base ever created. The quality of the data has been found to fulfil the accuracy requirements specified by the scientists for the Experiment.

As regards future activities, the data bank acquired during the preceding 12 months provides the necessary basis for the research and evaluation phase of the Experiment. More than 150 scientific institutions in the world will use these data in more than 500 projects during the period 1980–85. The scientific results of these studies are expected to assure the achievement of scientific objectives set for the Experiment.

(Based on a WMO press release)

## The observational systems of the Global Weather Experiment (summary of the data collection activities during the operational year December 1978–November 1979)

### 1. World Weather Watch (WWW) Global Observing System Surface-based:

*Surface-based:*

The global network of all 150 Members of WMO.

*c.* 9200 stations making observations at the surface.

*c.* 850 stations making observations in the upper atmosphere.

*c.* 7000 merchant ships making observations over the oceans.

In addition: 12 specially installed stations on remote islands making observations in the upper atmosphere.

*Space-based*

(a) *Five geostationary satellites*

Each geostationary satellite views the globe from a fixed position above the equator, taking cloud pictures in the visible and the infra-red wavebands every 30 minutes. From consecutive pictures the cloud motion can be inferred and this is a measure of the average wind velocity during the 30-minute period. Wind observations are therefore the most valuable products from geostationary satellites. The following table gives the average data volume for the entire system:

| Satellite | Position above equator | Average number of wind observations per day |
|---|---|---|
| GOES–West (USA) | 135°W | 1400 |
| GOES–East (USA) | 75°W | 1400 |
| Meteosat (ESA) | 0° | 850 |
| GOES–Indian Ocean (ESA/USA) | 60°E | 1500 |
| Himawari (Japan) | 140°E | 650 |
| Total | | 5800 |

(b) *Five polar-orbiting satellites*

Polar-orbiting satellites circle the earth in approximately 100 minutes, scanning the infra-red radiation of the surface and the atmosphere. From radiation data at various wavelengths, temperature and humidity of the atmospheric layers between surface and the stratosphere, which are important basic-state parameters for the description of the atmosphere as a physical system, can be inferred. The following polar-orbiting satellites provided data:

| Satellite | Operator | Launch date | Data |
|---|---|---|---|
| NOAA–5 | USA | 29 July 1976 | 1000 vertical profiles per day (until December 1978) |
| TIROS–N | USA | 13 October 1978 | 7500 vertical profiles per day, sea-surface temperature, data collection and platform location system (ARGOS) |
| NOAA–6 | USA | 27 June 1979 | As TIROS-N |
| NIMBUS–7 | USA | 24 October 1978 | Stratospheric profiles |
| METEOR | USSR | 25 January 1979 | Cloud images |

## 2. Observing systems specially implemented for the Global Weather Experiment

Special observing systems were planned and implemented, in particular to cover the vast data-sparse areas over the oceans and in the tropics. Some of these systems—owing to their high cost—could be operated only during two Special Observing Periods (SOPs):

(a) SOP I from 5 January to 5 March 1979.

(b) SOP II from 1 May to 30 June 1979.

*Tropical wind observing ships*

Altogether, ships from 23 countries participated. They were stationed in tropical oceanic regions around the globe, making observations at the surface and releasing balloons at least once daily for atmospheric soundings up to the stratosphere as summarized below:

| | Ships | Ship-days | Soundings | Average per day | Surface observations | Average per day |
|---|---|---|---|---|---|---|
| 5 Jan.–5 Mar. | 40 | 1480 | 3142 | 52 | 5900 | 98 |
| 1 May–30 June. | 43 | 1544 | 3538 | 58 | 6200 | 102 |

*Aircraft dropsonde system*

Aircraft able to drop sondes measuring wind, temperature and humidity between flight level and the surface operated from various bases over tropical regions and acquired data as summarized in the following table:

| | | Number of soundings | |
|---|---|---|---|
| Base | Region | 15 Jan.–20 Feb. | 10 May–8 June |
| Panama/Acapulco | East Pacific | 480 | 859 |
| Honolulu | Central Pacific | 1106 | 565 |
| Diego Garcia | Indian Ocean | 770 | 677 |
| Ascension Is. | Atlantic | 152 | 492 |
| Total | | 2508 | 2593 |
| Soundings per day | | 68 | 86 |

*Tropical constant-level balloons*

Balloons carrying sondes which measure temperature and pressure were released from bases on tropical islands and floated at a constant level of approximately 15 km above sea level. A satellite-borne

data-collection and location system (ARGOS) acquired their data and determined their position from changes in which the wind velocity was computed.

Bases were at Canton Island, Guam, and Ascension Island. A total of 213 balloons was launched in the two Special Observing Periods, providing an average number of 100 wind observations per day.

*Southern hemisphere drifting buoy system*

In the vast data-void areas of the southern-hemisphere oceans an improvement was particularly called for. Buoys were developed measuring atmospheric pressure and sea-surface temperature, and they were deployed at predetermined positions. As they drifted through the oceans, their data were collected and their positions were determined by the satellite-borne ARGOS system.

Seven countries contributed buoys to the system.

A total of 368 buoys was launched. At 30 November 1979, 130 buoys were still providing good data.

*Aircraft Integrated Data System (AIDS)*

This is a system installed on about 80 wide-bodied commercial aircraft to record automatically wind speed and direction and temperature and pressure along the aircrafts's track at intervals of about 200 km.

A total of 650 000 observations was collected. On average this results in 1800 observations per day, distributed almost over the entire globe.

### 3. Summary

The improvement obtained by the special observing systems in tropical latitudes of the globe shows the following assessment:

Normal *World Weather Watch* (average) resolution accounts for one wind observation every 850 km.
*Tropical wind observing ships* improved the resolution to one wind observation every 700 km.
*Aircraft dropsondes* added a further improvement resulting in one wind observation every 600 km.
*AIDS, satellites, and constant-level balloons* brought the resolution up to one wind observation every 420 km.
*Scientific planners* originally called for one wind observation every 400 km.

The scientific requirements in the tropics, calling for an improvement by a factor of 2, are therefore largely met. In extratropical latitudes, the density of the observations was even better than the requirement.

(Based on a WMO press release).

## The Ailsa Craig Experiment

The analysis of the data obtained during the Ailsa Craig Experiment (see *Meteorol Mag,* **108,** p. 250) is now complete. Ailsa Craig is a fairly isolated, nearly hemispherical island lying off the coast of Ayrshire. Flow characteristics were recorded with the aid of anemometers on masts, balloon-borne turbulence probes and the C–130 aircraft of the Meteorological Research Flight. During the Experiment mean velocities were measured in a three-dimensional turbulent separated flow—the first time this has been achieved. Several interesting and unexpected features have emerged, notably the presence of upward motion immediately downstream of the island—indicating that flow over the summit does not reattach in this region, contrary to previous ideas. The aircraft measurements have shown that there were powerful trailing vortices downstream of the island, with vertical velocities comparable with

horizontal flow speeds. Such motions have important implications for momentum transfer as well as constituting a hazard to aviation. The results will be assessed in the light of earlier numerical simulations.

### Recent developments in the implementation of the North West Radar Project

During December 1979 the first unmanned weather radar in the United Kingdom began to operate at Hameldon Hill near Burnley in Lancashire. This radar, a Plessey 45C (5·6 cm wavelength, 1° beamwidth) has been integrated into a microwave and land-line communications network to form a system which is the basis of the North West Radar Project (a project jointly sponsored by the Meteorological Office, the North West Water Authority (NWWA), the Water Research Centre, the Central Water Planning Unit, and the Ministry of Agriculture, Fisheries and Food).

The aims of the Project include the use of the radar data as an additional source of information for the development of quantitative precipitation forecasting techniques, and an assessment of the benefits of radar data to the NWWA. Data are transmitted in real time to the NWWA, to the Meteorological Office at Manchester Airport, and to the Meteorological Office Radar Research Laboratory at Malvern. At Malvern the data are archived, and some of the data are integrated in near-real-time with the radar data obtained from other radars at Camborne (Cornwall), Upavon (Wiltshire) and Clee Hill (Shropshire). (See *Meteorol Mag*, **108**, 1979, 161–184 and **109**, 1980, 75–77.)

## Obituary

We regret to record the death on 26 December 1979 of Mr D. G. Armour, Higher Scientific Officer. Downie Armour joined the Office as an Assistant in 1939 and for most of the war served first at various RAF stations in the United Kingdom and then in Canada. He returned to the United Kingdom early in 1944 and then, after training as a forecaster, was commissioned and posted to south-east Asia. After demobilization in 1946 he served at outstations until he joined the staff of the Training School in 1954. From 1955 to 1957 he worked at the London Forecast Office in Victory House—the section that was later developed into the London Weather Centre—and became well known to the general public through his appearances as a member of the team of television weather forecasters. After a few years in Germany he returned to his native Scotland, where he worked at the Glasgow Weather Centre for nearly four years and at the Meteorological Office, Edinburgh, for nearly a decade; while he was there he became known to many members of the Scottish agricultural community and built up a large and valuable circle of professional contacts. At the time of his death he was stationed at Edinburgh Airport (Turnhouse).

Downie Armour was a keen Rugby football player in his youth and was a long-standing member of the Boroughmuir F.P. club. He was Secretary and Treasurer of the Scottish Centre of the Royal Meteorological Society from 1967 to 1975, and served as Chairman and Vice-President from 1976 to 1977.

He had a most likeable and friendly personality with a good deal of quiet humour.

## Meteorological Magazine—increase in annual postal subscription

With effect from 4 February 1980 the annual postal subscription rate for the *Meteorological Magazine* was raised from £20.82 to £21.18. This change reflects the recent increase in postal charges; the price for over-the-counter sales remains £1.60 per copy.

## Correction

Examples of banded rainfall distributions in potentially unstable conditions over southern England, by B. A. Hall, *Meteorol Mag*, **109**, 1980, 1–17.

In Figure 1(d) as printed on page 5 of the above-mentioned article, an area in the extreme south-west of England is shown with a form of hatching which is not to be found in the associated key.

A corrected version of this Figure is printed below.

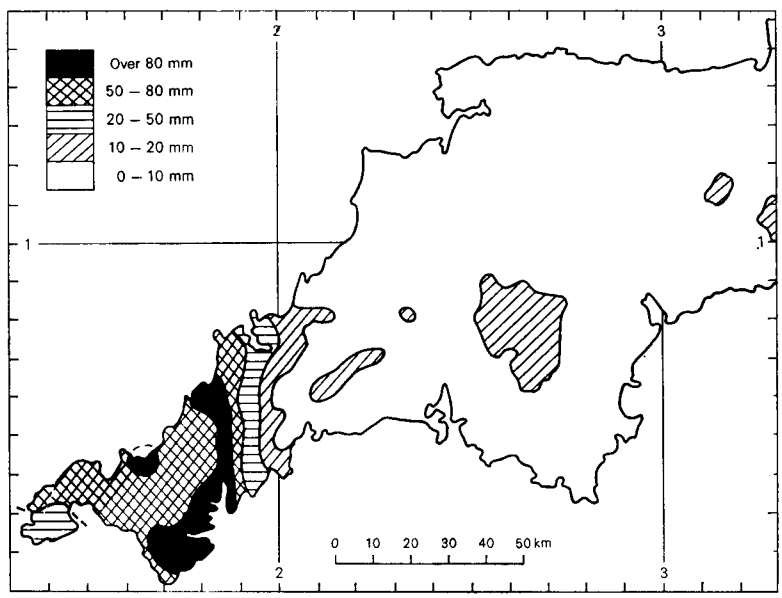


Figure 1(d). Rainfall totals for 24 hours from 09 GMT on 5 October 1977 to 09 GMT on 6 October 1977.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ, and marked 'For Meteorological Magazine'.

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

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